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OXYGEN-FUEL BURNER WITH INTEGRAL STAGED OXYGEN SUPPLY

BACKGROUND AND SUMMARY OF THE INVENTION

This application is a continuation-in-part of application Ser. No. 08/092,008, filed Jul. 15, 1993, now U.S. Pat. No. 5,431,559, issued on Jul. 11, 1995.

The present invention relates to burner assemblies, and particularly to oxygen-fuel burner assemblies. More particularly, the present invention relates to a burner having a fuel-delivery system and a staged oxygen-supply system.

One challenge facing the burner industry is to design an improved burner that produces lower nitrogen oxide emissions during operation than conventional burners. Typically, an industrial burner discharges a mixture of fuel and either air or oxygen. A proper ratio of fuel and air is established to produce a combustible fuel and air mixture. Once ignited, this combustible mixture burns to produce a flame that can be used to heat various products in a wide variety of industrial applications. Combustion of fuels such as natural gas, oil, liquid propane gas, low BTU gases, and pulverized coals often produce several unwanted pollutant emissions such as nitrogen oxides (NO_x), carbon monoxide (CO), and unburned hydrocarbons (UHC).

Burners that combine oxygen with an atomized fuel and oxygen mixture to produce a combustible mixture are known. See, for example, U.S. Pat. No. 5,092,760 to Brown and Coppin. Burners having oxygen-enrichment systems are also known as disclosed in the *IHEA Combustion Technology Manual,* Fourth Edition (1988), pp. 320–21, published by The Industrial Heating Equipment Association of Arlington, Va.

Burners were developed to burn a mixture of fuel and pure oxygen in an attempt to lower the amount of NO_x produced during combustion. Atmospheric combustion air contains approximately 79% nitrogen (N_2) and pure oxygen contains no nitrogen. It has been observed that the higher flame temperatures brought on by burning a mixture of fuel and pure oxygen has caused the conversion of fuel-bound N_2 into NO_x to increase. Additionally, new technology that allows on-site generation of combustion oxygen has been developed by oxygen suppliers. This on-site generated oxygen is not pure and can contain as much as 10% nitrogen by volume. This additional nitrogen, in contact with the high-temperature oxy-fuel flame, represents an additional source of NO_x emissions.

A burner assembly designed to burn fuel more completely using a lower flame temperature would lead to lower nitrogen oxide emissions. What is needed is a burner assembly that is able to burn a fuel and oxygen mixture without generating a lot of unwanted nitrogen oxide emissions. A staged oxygen burner designed to direct oxygen to various regions of a flame produced by the burner using modular components and easily manufactured precision oxygen-flow metering apparatus would lead to lower nitrogen oxide emissions and thus be a welcomed improvement over conventional burner assemblies. Ideally, an improved staged oxygen burner would be configured to accept various fuel nozzles to permit a user to burn either fuel gas or fuel oil at the option of the user.

According to the present invention, a burner assembly is provided for combining oxygen and fuel to produce a flame. The burner assembly includes a burner block formed to

include a flame chamber having inlet and outlet openings, bypass means for conducting oxygen outside of the flame chamber to the outlet opening of the flame chamber, and means for discharging fuel into the flame chamber formed in the burner block.

The burner assembly also includes an oxygen-supply housing including chamber means for receiving a supply of oxygen and a base wall adjacent to the burner block. The base wall is formed to include first aperture means for discharging oxygen from the chamber means into the flame chamber and second aperture means for discharging oxygen from the chamber means into the bypass means.

In preferred embodiments, pure oxygen under pressure is admitted into the chamber means. Some of this pressurized oxygen is discharged into the inlet opening of the flame chamber through the first aperture means formed in the base wall. The rest of this pressurized oxygen is discharged from the chamber means through the second aperture means formed in the base wall to bypass the flame chamber and follow predetermined paths to the outlet opening of the flame chamber.

Illustratively, a flow-metering device is provided to control flow of oxygen discharged through the first aperture means into the inlet opening of the flame chamber. The flow-metering device is formed to include a first-stage oxygen port controlling flow of oxygen into the inlet opening of the flame chamber. The second aperture means defines a second-stage oxygen port controlling flow of oxygen to the outlet opening of the flame chamber.

By establishing a fixed ratio between the effective cross-sectional area of the first-stage oxygen port and the effective cross-sectional area of the second-stage oxygen port, it is possible to proportion and control the relative flow of oxygen to each of the inlet and outlet openings of the flame chamber. Illustratively, a first set of holes is formed in the flow-metering device to define the first-stage oxygen port and a second set of holes is formed in the base wall to define the second-stage oxygen port. Advantageously, it is possible to change the fixed ratio described above simply by varying the diameter of the holes formed in the base wall at the time that those holes are created (e.g., drilled or milled).

Some of the pressurized oxygen discharged from the oxygen-supply housing chamber means (i.e., "first-stage oxygen") passes through the first aperture means and the first-stage oxygen port formed in the flow-metering device and then mixes with fuel provided by the discharging means in a first-stage region inside the flame chamber. This combustible fuel and oxygen mixture can be ignited to define a flame having a root portion in the flame chamber and a tip portion outside the flame chamber.

The burner block is also formed to include oxygen-discharge ports around the outlet opening of the flame chamber and oxygen-conducting means for conducting oxygen along one or more paths through the burner block and outside of the flame chamber to the oxygen-discharge ports. The rest of the pressurized oxygen discharged from the oxygen-supply housing chamber means passes through the second aperture means formed in the base wall into the oxygen-conducting means formed in the burner block. This "second-stage" oxygen passes through the oxygen-discharge ports and is ejected from the burner block into a downstream second-stage region containing a portion of the flame and lying outside the flame chamber.

In preferred embodiments, the burner block is made of a refractory material and includes an outside wall formed to include the flame chamber inlet opening and a plurality of

oxygen-admission ports around the inlet opening. The burner block also includes a furnace wall configured to lie in a furnace and formed to include the flame chamber outlet opening and the plurality of oxygen-discharge ports around the outlet opening.

Illustratively, the burner block is also formed to include a plurality of oxygen-conducting passageways. These passageways are formed during casting of the burner block. Each passageway extends through the burner body to connect one of the oxygen-admission ports to one of the oxygen-discharge ports. Essentially, these passageways are arranged to bypass the flame chamber and deliver second-stage oxygen to the second-stage region downstream of the flame chamber. Illustratively, the second-stage region lies in a furnace adjacent to the burner block and the flame produced by the burner assembly heats products in the furnace.

The oxygen-supply housing is provided to hold temporarily a supply of pressurized combustion oxygen for use in the burner assembly. In use, a continuous stream of pressurized oxygen is admitted into the oxygen-supply housing using any suitable means. Some of that pressurized oxygen is distributed to the first-stage region through the first aperture means and the rest of that pressurized oxygen is distributed by the bypass means to the second-stage region using the oxygen-conducting passageways formed in the burner block.

The burner assembly in accordance with the present invention introduces combustion oxygen into two regions or combustion zones. The first-stage combustion zone is near the root of the flame inside the flame chamber and the second-stage combustion zone is in the furnace itself in a location downstream from the flame chamber and nearer to the tip of the flame. Advantageously, by withholding a portion of the combustion oxygen from the root of the flame, the fuel partially burns and the fuel-bound nitrogen is converted into reducing agents. These nitrogenous compounds are subsequently oxidized to elemental nitrogen, thereby minimizing the generation of fuel nitrogen oxides. Also, the peak flame temperature is lowered in the fuel-rich first-stage combustion zone since the generated heat dissipates rapidly. This reduction in flame temperature reduces the formation of nitrogen oxides which are temperature-dependent. In the second-stage combustion zone, additional oxygen is injected through the burner block oxygen-discharge ports to complete combustion and optimize flame shape and length.

Illustratively, the burner assembly includes several modular components that can be assembled and changed easily. An oxygen-supply housing can be connected to or disconnected from a burner block using a frame and removable fasteners. A fuel nozzle module is mounted in the oxygen-supply housing so that it can be removed easily. By replacing a gas-fuel nozzle module with an oil-fuel nozzle module, it is possible to convert the burner assembly from a gas-burning unit to an oil-burning unit.

Additional features and advantages of the invention will become apparent to those skilled in the art upon consideration of the following detailed description of preferred embodiments exemplifying the best mode of carrying out the invention as presently perceived.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description particularly refers to the accompanying figures in which:

FIG. 1 is a perspective view of a burner assembly in accordance with the invention showing an oxygen-supply

housing coupled to a burner block, an oxygen-supply source coupled to the oxygen-supply housing, and a fuel supply source coupled to a gas-fuel nozzle module mounted in the oxygen-supply housing;

FIG. 2 is a front elevation view taken along line 2—2 of FIG. 1 showing four oxygen-discharge ports formed in the furnace wall of a burner block and arranged to lie around the outlet opening of a flame chamber formed in the burner block and showing three kidney-shaped oxygen-flow apertures formed in an oxygen flow-metering device and arranged to surround a fuel-discharge head of the gas-fuel nozzle module;

FIG. 3A is a side elevation view taken along line 3A—3A of FIG. 2 showing the burner block, the oxygen-supply housing containing a gas-fuel nozzle module, the fuel-discharge head of the gas-fuel nozzle module at the inlet end of a flame chamber in the burner block, first-stage means for supplying oxygen from the oxygen-supply housing through the oxygen flow-metering device appended to the fuel-discharge head into a first-stage combustion zone in the flame chamber, and second-stage means for conducting oxygen from the oxygen-supply housing to a second-stage combustion zone downstream of the flame chamber using bypass passages formed in the burner block and the frame joining the oxygen-supply housing to the burner block;

FIG. 3B is a perspective view of the fuel-discharge head of the gas-fuel nozzle module illustrated in FIGS. 1 and 2 showing three kidney-shaped oxygen-flow apertures formed in a ring-shaped oxygen flow-metering device appended to the fuel-discharge head;

FIG. 3C is an enlarged sectional view of a portion of the burner assembly taken along line 3C—3C of FIG. 2 showing a base wall of the oxygen-supply housing, a wall aperture formed in the base wall, a larger diameter oxygen-conducting channel formed in the frame joining the oxygen-supply housing to the burner block, and an oxygen-conducting passageway formed in the burner block;

FIG. 4 is an alternative embodiment of the burner assembly of FIG. 3A showing an annular oxygen-distributing manifold provided between the frame and the burner block;

FIG. 5 is a front elevation view taken along line 5—5 of FIG. 4 showing four arcuate oxygen-discharge ports formed in the furnace wall of the burner block and arranged to lie around the outlet opening of the flame chamber formed in the burner block;

FIG. 6 is an enlarged sectional view of a portion of the burner assembly taken along line 6—6 of FIG. 4 showing a base wall of the oxygen-supply housing, a wall aperture formed in the base wall, a larger diameter oxygen-conducting channel formed in the frame joining the oxygen-supply housing to the burner block, a circular oxygen-distributing manifold provided between the frame and the burner block, and an oxygen-conducting passageway formed in the burner block;

FIG. 7 is another alternative embodiment of the burner assembly of FIG. 3A showing an oil-oxygen atomizing fuel nozzle module mounted in the oxygen-supply housing; and

FIG. 8 is a front elevation view taken along line 8—8 of FIG. 7.

DETAILED DESCRIPTION OF THE DRAWINGS

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~~As shown in FIG. 1, a staged oxygen burner assembly 10~~ includes a burner block 12, a frame ~~14 mounted~~ on an inlet end of the burner block ~~12, and~~ a hollow oxygen-supply housing 16 moun~~ted on~~ the frame 14 by means of removable

fasteners 18. A fuel nozzle 20 is positioned to lie inside the hollow oxygen-supply housing 16 and is retained in place by means of a removable collar 22. It is easy to replace the fuel nozzle 20 because of the modular nature of the staged oxygen burner assembly 10. For example, to convert the staged oxygen burner assembly 10 from a gas-fired unit to an oil-fired unit, it is necessary only to replace the gas-fuel nozzle module shown in FIG. 3A with the oil-fuel nozzle module shown in FIG. 7.

Pressurized oxygen is delivered to hollow oxygen-supply housing 16 from oxygen supply 24 through conduit 26 using any suitable means. Pressurized fuel is delivered to fuel nozzle 20 from fuel supply 28 through conduit 30 using any suitable means. The oxygen-supply housing 16 cooperates with frame 14 and burner block 12 to deliver some of the combustion oxygen in oxygen-supply housing 16 to a first-stage region near the root of a flame inside the burner block 12 and the rest of the combustion oxygen to a second-stage region at a point closer to the tip of the flame outside the burner block 12. This staged oxygen burner assembly 10 meters the combustion oxygen to each stage so as to minimize unwanted nitrogen oxide emissions. The apparatus used to accomplish this oxygen-metering function is precise and easy to manufacture and use and will be described in more detail below.

The burner block 12 is formed to include a flame chamber 32 as shown in FIGS. 2 and 3A. The flame chamber 32 has an inlet opening 34 at one end and an outlet opening 36 at its opposite end. Illustratively, as shown in FIG. 2, the first-stage oxygen 37 is discharged into the inlet opening 34 of the flame chamber 32 through three kidney-shaped oxygen-flow apertures 38 and the second-stage oxygen 39 is discharged at points adjacent to the outlet opening 36 of the flame chamber 32 through four oxygen-discharge ports 40, 41, 42, 43.

As shown in FIG. 3A, burner assembly 10 is used in industrial processes to produce a flame 44 that extends into a furnace 46. Various products 48 can be conveyed through the furnace 46 to be treated or processed using heat generated by flame 44. Burner assembly 10 is configured to heat products 48 conveyed through the furnace 46 and to minimize the amount of nitrogen oxide produced during combustion. In particular, burner assembly 10 includes a staged oxygen supply system that operates to deliver some of the combustion oxygen to a first-stage region near the root of flame 44 and the rest of the combustion oxygen to a second-stage region at a point closer to the tip of flame 44. By diverting some of the combustion oxygen toward the tip of flame 44, it is possible to reduce nitrogen oxide emissions. Burner assembly 10 can be used in a wide variety of applications due to its enhanced emissions performance.

As shown in FIG. 3A, burner assembly 10 is configured to include a natural gas burner 69 of the type disclosed in U.S. Pat. No.

[4,690.635] 4,690,635.

Illustratively, the burner 69 is mounted in the oxygen-supply housing 16 in the manner shown in FIG. 3A.

Oxygen-supply housing 16 includes a base wall 52 coupled to frame 14 by the removable fasteners 18 and a hollow shell 54 appended to the base wall 52 to define a chamber 56 for receiving a supply of pressurized oxygen 57 from the oxygen supply 24. The hollow shell 54 illustratively has a pyramidal shape and four triangular side walls 58. One of these triangular side walls 58 is formed to include an oxygen-admission port 60 coupled to the conduit 26 carrying pressurized oxygen from oxygen supply 24. Although shell 54 could have a round, square, rectangular,

or other shape, a pyramidal shape is presently preferred to conserve space in a furnace application.

As shown in FIGS. 1 and 2, the hollow shell 54 includes a tip 62 at one end and the four triangular side walls 58 extend in diverging relation from the tip 62 to the base wall 52. Illustratively, the tip 62 is somewhat cylindrical in shape and is formed to include a central aperture 64. A portion of the base wall 52 under the hollow shell 54 is formed to include a first aperture 66 and four second apertures 68 around the first aperture 66. The pressurized first-stage oxygen 37 is discharged from the oxygen-supply housing chamber 56 through the first aperture 66 formed in the base wall 52. At the same time, the pressurized second-stage oxygen 39 is discharged from the oxygen-supply housing chamber 56 through the second apertures 68 formed in the base wall 52. Illustratively, these second apertures 68 lie in radially spaced-apart relation to the first aperture 66 and in circumferentially spaced-apart relation to one another.

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~~A~~ gas conduit 70 is disposed within housing ~~12 and has~~ means thereon for directing a gaseous fuel therethrough to be expelled from gas conduit 70 and to mix with the oxygen for burning in a sustainable flame. Gas conduit 70 may preferably have one or more O-ring seals 72 disposed at a mounting fixture 71 formed near the outer end of the gas conduit for effectuating a seal with a rear lip portion 75 of ~~the tip 62 of hollow shell 54.~~

The natural gas burner 69 further includes a gas conduit tip or fuel-discharge head 73 connected to gas conduit 20 by gas conduit channel 76 and includes a substantially flat exterior tip face surface 78 as shown best in FIG. 3B. Exterior tip face 78 has a substantially frustoconical-shaped prominence 80 disposed thereon and protruding from tip face 78. The flow-metering device 74 is a ring-shaped flange that is formed to include the three kidney-shaped oxygen-flow apertures 38 and appended to gas conduit tip 73 as shown in FIGS. 3A and 3B. Once the natural gas burner 69 is installed in the oxygen-supply housing 16 as shown in FIG. 3A, the frustoconical-shaped prominence 80 is positioned to extend into the inlet opening 34 of flame chamber 32 and the flow-metering device 74 is positioned to lie between the first aperture 66 in base wall 52 and the inlet opening 34.

Gas conduit tip 73 also includes a central gas channel 82 centrally disposed therethrough and terminating at the proximal end of frustoconical-shaped prominence 80 to form substantially a knife edge-shaped rim 84 thereon. Such knife edge-shaped rim 84 structure functions to delay combustion for a few microseconds and to provide no substantial available surface for the accumulation of carbon thereon. The opening of central gas channel 82 is preferably disposed in a plane spaced at a selected distance away from the plane of tip face 78.

The oxygen-flow apertures 38 formed in flow-metering device 74 cooperate to define a first-stage oxygen port having a first effective cross-sectional area that is equivalent to the sum of the cross-sectional areas of the three kidney-shaped oxygen-flow apertures 38. In a presently preferred embodiment, oxygen flow apertures 38 are disposed in a circular array, which array is substantially concentric with central gas channel 82. These oxygen-flow apertures 38 function to pass pressurized oxygen that is discharged from the oxygen-supply housing chamber 56 through the first aperture 66 into the burner block flame chamber 32 through its inlet opening 34. In operation, pressurized oxygen from oxygen-supply housing 16 passes through oxygen-flow apertures 38 into the flame chamber 32 to mix with natural

gas or other gaseous fuel supplied through central gas channel **82** of gas conduit tip **73**. This combustible mixture is ignited in flame chamber **32** to produce flame **44** using any suitable means.

The oxygen-supply housing **16**, as shown in FIGS. **1** and **3A**, is connected to a metal support block holder or frame **14** having a refractory burner block **12** retained in position with a suitable high temperature cement (not shown). The burner block **12** is made of, for example, zirconia or ZEDMUL 20C, and is formed to include a longitudinally extending and diverging flame chamber **32**. The frame **14** has a flange portion **86** for attachment to the wall **88** of furnace **46**. As shown in FIG. **3A**, the burner assembly **10** includes a nose portion **90** provided with a central discharge orifice or annular opening **92**. The nose portion **90** has a mounting flange **94** adjacent its inlet end which is suitably secured to the base wall **52** using mounting pins as shown in FIG. **3A**. A gasket **96** is provided between mounting flange **94** and base wall **52** and the gasket **96** is formed to include a large opening at first aperture **66**.

As shown in FIG. **3A**, the burner assembly **10** is configured to provide a first-stage combustion zone **110** in a region inside flame chamber **32** near the root **112** of flame **44** and a second-stage combustion zone **114** in a region inside furnace **46** and outside of the flame chamber **32** toward the tip **116** of flame **44**. A continuous stream of combustion oxygen **57** is supplied to oxygen-supply housing **16** through supply pipe **26** to ensure that housing **16** always contains pressurized oxygen. A first stream **37** of combustion oxygen is discharged from housing **16** into the first-stage combustion zone **110** through central discharge orifice **92** in nose portion **90** as described above. A second stream **39** of combustion oxygen is discharged from housing **16** into the second-stage combustion zone **114** through several passageways bypassing the flame chamber **32** as shown in FIG. **3A**.

As shown in FIGS. **2**, **3A**, and **3C**, burner block **12** is formed to include four longitudinally extending bypass passageways **40**, **41**, **42**, and **43** for conducting the second stream **39** of combustion oxygen to the second-stage combustion zone **114** without passing through the flame chamber **32** formed in the burner block **12**. Burner block **12** includes an outside wall **118** that is formed to include an inlet opening **120** into each of the oxygen-conducting passageways **40**, **41**, **42**, and **43** and a furnace wall **122** that is formed to include an outlet opening for each of the oxygen-conducting passageways **40**, **41**, **42**, and **43**. The flame chamber **32** has an inlet opening **34** formed in an inner portion of burner block **12** and an outlet opening **36** formed in furnace wall **122** of burner block **12**. As shown in FIG. **2**, the four outlet openings are arranged in uniformly circumferential spaced-apart relation around the nozzle **20** and the inlet opening **34** of the flame chamber **32**. The four outlet openings are also arranged to lie in radially equidistant relation from the burner tip opening **82** as shown best in FIG. **2**.

Four oxygen-conducting channels are formed in frame **14** to conduct the second stream **39** of combustion oxygen from outlets **68** formed in the oxygen-supply housing **16** to the oxygen-conducting passageways **40**, **41**, **42**, and **43** formed in the burner block **12**. Two of these oxygen-conducting channels **124**, **126** are shown in FIG. **3A** and one oxygen-conducting channel **128** is shown in greater detail in FIG. **3C**. Each oxygen-delivery channel illustratively includes an inlet end **130**, an outlet end **132**, and a straight portion **134** between the inlet and outlet ends **130** and **132** as shown in FIG. **3C**. It will be understood that the number and shape of the oxygen-conducting channels can vary depending upon the application and also upon the location of the housing **16**

and the inlet openings 120 into the oxygen-conducting passageways formed in the burner block 12.

The second apertures 68 formed in the base wall 52 are sized to regulate the flow of the second stream 39 of pressurized oxygen through the oxygen-conducting channels formed in frame 14 and the oxygen-conducting passageways 40, 41, 42, and 43 formed in the burner block 12 to the second-stage combustion zone 114.

~~The oxygen-conducting channels formed in frame 14 and the oxygen-conducting passageways 40, 41, 42 and 43 formed in the burner block 12 cooperate to define an oxygen conductor conduit configured to conduct oxygen from the second apertures 68 formed in the base wall 52 to the second-stage combustion zone 114.~~

The internal diameter of each second aperture 68 is less than the internal diameter of the corresponding oxygen-conducting channel 128 formed in the frame 14 and the internal diameter of the corresponding oxygen-conducting passageway 41 formed in the burner block 12 as shown, for example, in FIG. 3C. Conveniently, the size of each second aperture is selected to produce the lowest nitrogen oxide emission for the desired flame shape and luminosity for the particular burner application.

The effective cross-sectional open area of the second apertures 68 is set when those apertures 68 are drilled in the base wall 52. By reducing the internal diameter of one or more of the second apertures 68 as compared to the relatively larger internal diameters of the corresponding downstream channels and passageways formed, respectively, in the frame 14 and burner block 12, it is possible to limit or otherwise regulate and control the flow of pressurized oxygen 39 that passes to the second-stage combustion zone 114. It will be understood that the flow of the second stream of oxygen 39 is limited by the size of the second apertures 68 since the cross-sectional area of each aperture is preferably less than the cross-sectional area of its corresponding downstream frame channel and burner block passageway. Although it is within the scope of the present invention to make the open area of one or more second apertures 68 greater than the open area of the corresponding downstream channels and passageways, such a design would make it more difficult to change the flow of second-stage oxygen since it would now be necessary to vary the cross-sectional areas of one or more of the frame channels or burner block passageways.

It is within the scope of the present invention to proportion the flow of pressurized oxygen discharged from the oxygen-supply housing 16 into the first-stage combustion zone 110 and the second-stage combustion zone 114 by forming the oxygen-flow apertures 38 in the flow-metering device to have an effective cross-sectional area that is fixed in relation to the effective cross-sectional area of the second apertures 68 formed in base wall 52. Essentially, these two effective cross-sectional areas are proportioned or ratioed to create a staged oxygen burner assembly having low nitrogen oxide emissions. In a presently preferred embodiment, the effective cross-sectional area of the kidney-shaped oxygen-flow apertures 38 (i.e., the first-stage oxygen port) is set during the manufacture of the flow-metering device 74 appended to the natural gas burner 69. The ratio of oxygen flow between the first-stage combustion zone 110 and the second-stage combustion zone 114 can then be varied to suit any particular application by drilling or otherwise forming the second apertures 68 in the base wall 52 of the oxygen-supply housing 16. It will be understood that stock housings

16 with undrilled base walls 52 can be adapted easily to change the oxygen flow ratio between the first- and second-stage combustion zones 110, 114 simply by selecting an internal diameter for each of the second apertures 68 that is calculated to achieve the desired result. Because of the modular nature of burner assembly 10, it is possible to change such staged oxygen flow ratio simply by removing the old oxygen-supply housing 16 having one set of second

apertures 68 formed in the base wall 52 and replacing it with a new oxygen-supply housing having a different set of second apertures 68.

By shutting off or varying the flow of combustion oxygen 39 through one or more of oxygen-conducting channels formed in frame 14 and oxygen-conducting passageways 40, 41, 42, and 43 formed in burner block 12, it is possible to control the luminosity and shape of flame 44. It has been observed that flame 44 tends to bend slightly toward an oxygen source and that a non-geometrically perfect flame may exhibit less nitrogen oxide (perhaps as a result of some imbalance in mixing fuel and oxygen).

Flame 44 can include a yellow luminous portion and a "cooler" blue non-luminous portion. In the glass industry, it is often preferred to produce a flame having a luminous portion adjacent to glass 48 heated in furnace 46. Glass furnace operators typically prefer to position the "cooler" non-luminous portion of the flame 44 facing toward the roof 136 of the furnace 46. This allows the furnace crown or roof 136 to run cooler, lose less heat, and extend its useful life. It has been observed that supplying oxygen to a flame causes the oxygen-rich portion of the flame to become more non-luminous.

It will be understood that is possible to vary the internal diameter of one or more second apertures 68 relative to the other second apertures 68 to control the luminosity and shape of flame 44. It is also within the scope of the present invention to eliminate (e.g., never drill) one or more second apertures 68 in base wall 52 to block flow of pressurized oxygen into and through one or more frame channels and burner block passageways to reach the second-stage combustion zone 114. Reference is hereby made to parent application No. 08/092,008, filed Jul. 15, 1993, which is incorporated by reference herein, for a more detailed discussion of means for regulating oxygen flow to vary flame luminosity and shape.

The burner assembly 138 shown in FIGS. 4–6 is similar to the burner assembly 10 shown in FIG. 3A. In the embodiment of FIGS. 4–6, the burner block 12' is formed to include an annular channel 140 surrounding the nose portion 90 and interconnecting each of oxygen-conducting passageways 40', 41', 42', and 43' in fluid communication

The frame 14' includes means for covering the annular channel 140 to define a circular oxygen-conducting passageway 142 therebetween. This circular passageway 142 receives pressurized oxygen 39 from oxygen-conducting channels formed in the frame 14' and connected to the second apertures 68 formed in the base wall 52 and transfers that pressurized oxygen 39 into the oxygen-conducting passageways 40', 41', 42', and 43' formed in the burner block 12'. Two outlet apertures 144, 146 from two of the oxygen-conducting channels 148, 150 formed in frame 14 are shown in FIG. 4.

[AS] As shown in FIG. 5, the oxygen-conducting passageways 40', 41', 42', and 43' formed in burner block 12' have an arcuate shape and terminate in annular openings extending around the outlet opening 36 of the flame chamber 32. As shown in FIGS. 5 and 6, pressurized oxygen passes in sequence from chamber 56 in oxygen-supply housing 16 through second apertures 68, frame channels 149, and outlet apertures 144, 145, 146, and 147, circular passageway 142, and annular oxygen-conducting passageways 40', 41', 42', and 43' to the second-stage combustion zone 114.

The only difference between the embodiment of FIG. 7 and the embodiment of FIG. 3A is the type of fuel nozzle module mounted in the oxygen-supply housing 16. A natural gas nozzle 69 is used in the embodiment of FIG. 3A and an